DIGITAL SPECTRAL IDENTIFIER-CONTROLLER

AND RELATED METHODS

Cross Reference to Related Applications. This application is a Continuation-in-Part of Application, Serial No. 09/343,855 filed 06/30/99 entitled Digital Spectral Identifier-Controller and Related Methods.

Field of Invention. This invention is primarily directed to an electronic apparatus and method for identifying objects and species of objects such as plants in an agricultural field. It includes a wide spectrum light scanning and sensor unit having a digital identifier. More particularly, the preferred embodiment includes an apparatus for selectively identifying 1) all plants, 2) all plants other than agricultural crops 3) specific plants within a field, such as weeds of a specific species.

This invention is also directed to a long recognized problem of selectively applying chemicals to specific plants in a field while avoiding the application of such chemicals to other plants. The practical and economic needs for such a device are substantial. First, if not selectively applied, the herbicide may adversely affect the growing agricultural crop. Second, a substantial portion of a herbicide may be wasted because it is applied to the ground surface and not to the vegetation thus reducing the cost effectiveness of the chemical. Third, application of herbicide to the ground contributes to pollution and long term unknown environmental problems. Fourth, different herbicides have different effects upon different weeds and selective application of the correct herbicide to the proper weeds would achieve the most cost effective eradication.

The plant identification component of my invention may also be combined with a

mechanical weed eradicator such that the weeds may be selectively eradicated by a knife, water jet or other tool upon identification of the undesirable plant or weed. In addition, it can be used to selectively apply growth regulators, inhibitors and other chemicals to selected crop plants.

Illustrative of benefits and one field of use of this invention is the identification and spraying of weeds in Roundup® corn or cotton, *i.e.*, plants whose genetics have been altered so as to be unaffected by Roundup® herbicide. Presently, these crops are planted and the Roundup® herbicide is subsequently applied over the entire crop, the ground and weeds of all types. At a recommended application rate of a quart per acre and a cost of approximately $37.50 per gallon, the farmer's total cost of applying the Roundup® herbicide may be $10.00 per acre for each application. Yet, in many fields, less than 10% of this amount of herbicide is needed to kill only the weeds. This invention permits identification of the weeds and limited, but direct application of herbicide to the weeds for a cost savings that may well approach $9.00 per acre in many applications. And clearly, where Monsanto Corporation, the manufacturer of Roundup® herbicides, recommends two or more applications to the Roundup® corn or cotton, this invention will permit substantial savings in the cost of growing these crops.

This invention also applies to the identification of other plants and the application of other chemicals to those plants. For example, growth inhibitors are applied to crops in some years to limit the growth of the plant while simultaneously enhancing the fruit production of the crop. This invention will permit the selective application of the inhibitor to the plant without excess application to the ground and the weeds.

The invention of this application also applies to the field of plant stress and condition analysis. Its capacity to collect wide spectrum light data reflected from a plant enables the use of

the invention to quantify the condition of the plant, including the existence of plant stress at a very early stage. More importantly, the invention permits the collection of detail wide spectrum information that cannot be read by the human eye. Such is believed to provide early revelation of the need for fertilizers, moisture, growth inhibitors, or the presence of nematodes and fungi. Importantly, the invention permits an objective method of analyzing plants that avoids subjective and varying interpretations and conclusions that might otherwise result from individual observation.

This invention also has application in other fields such as identification of the condition of plants and objects including fluids and animal tissue. For example, it may be applied to the identification of the ripeness and grading of fruits and vegetables such as tomatoes, quality control of the color of finished objects and the identification of normal, diseased or abnormal tissue in the human body directly or through a scope.

The Prior Art. The prior art has long recognized the problem and need for plant recognition and the application of chemicals only to certain plants. In this decade one popular approach is a spray vehicle having a support bar with seats for three or more laborers holding manually operated spray guns. As the vehicle travels down the rows at a slow speed, the laborers selectively apply a herbicide to any weeds encountered. This is one expensive effort to eliminate the common practice of hoeing weeds in crops such as cotton. In addition to this approach, substantial efforts have been made to develop improved plant identification methods. In large part, the art has focused on the broad identification of vegetation through two basic methods: 1) spatial detection by plant location in the middle of the rows by mechanical means and 2) detection by the use of light such as breaking a light beam or

1   reflection comparison of light beams composed primarily of red and infra-red light

2   wavelengths or of a few wavelengths of light such as the primary colors.

3   For example, U.S. Patent 4,206,569, which issued in 1978 to Randolph, teaches the

4   detection of undesirable plants by their position between rows of plants. In one embodiment,

5   Randolph teaches the use of a "feeler paddle" to physically feel or sense the position of a plant

6   within the row and to actuate a switch which, in turn, activates a sprayer to apply a herbicide to

7   the plant. In another embodiment, the Randolph patent teaches the use of an infrared light

8   source and sensor to detect the presence of a weed between the rows of plants. Interruption of

9   the infrared light beam indicates the presence of a weed that causes activation of a solenoid

10   valve which applies herbicide to the plant.

11   U.S. Patent No. 5,144,767 which issued in 1992 to McCloy *et. al.* discloses an

12   agricultural sprayer that detects the presence of vegetation by sensing the reflected red and

13   infrared wavelengths and the incident light energy. Subsequently, a CPU determines the ratio of

14   reflected red and infrared light to the incident light, compares them with those of a lookup table

15   that is tailored with values indicative of vegetation. If there is a comparison, then a herbicide

16   spray is applied to the vegetation. McCoy notes that his device identifies green vegetation

17   because it is "quite dissimilar to all other surfaces when analyzing the reflectance values of both

18   wave-bands," *i.e.*, the red and infra-red wave bands. McCoy does not suggest any capability to

19   distinguish between types of green vegetation, *i.e.*, between weeds of different types or between

20   weeds and crop plants.

21   Another prior art device is that advertised as the Patchen ™ Selective Spray Systems of

22   101A Cooper Court, Lost Gatos, CA 95030, a company that is believed to be a wholly-owned

1 subsidiary of Deere & Company of Moline, Illinois. On belief, this unit uses reflections from

2 bursts of light to distinguish between soil and weeds that are spatially located in the middle of

3 the row. A Patchen advertisement states:

4   "The spray system will spray only weeds, not bare ground. Make No

5   mistake—this is a revolutionary achievement that will deposit dollar savings

6   directly into you bank account."

7 As far as can be determined, this unit has some ability to distinguish between plants and bare

8 ground, but not between crops and weeds. Neither can it identify specific types of weed.

9 Patents numbered 5,763,873, 5,585,626, 5,389,781 and 5,296,702 are believed to be directed to

10 this device. They represent at least six years of development work in this field.

SUMMARY OF INVENTION

12   The present inventions are primarily directed to a wide spectrum light scanning and

13 sensor unit having a digital identifier. The preferred application focuses on a low cost plant

14 identifier or recognition system that may be mounted upon a moving vehicle for accurately

15 identifying and distinguishing between different species of plants at conventional agricultural

16 spraying speeds. This identifier may be combined with an apparatus for selectively applying

17 herbicides, plant inhibitors, growth regulators, or selectively actuating a tool such as a knife or

18 water jet for eradicating the plant. Other applications include grading of fruits and vegetables,

19 analysis of plant and animal tissue, etc.

20   The preferred embodiment of the plant identifier includes an electromagnetic sensing

21 mechanism that is not limited to identification premised upon a few wavelengths of light such as

22 red and infrared. This invention is preferably, an accurate wider spectrum electromagnetic

1   method and apparatus capable of accurately identifying and discriminating between different

2   types of vegetation as well as between vegetation and soil of any type and color.

3   The invention includes a wide spectrum scanning and sensing unit that having slits

4   through which reflected light is transmitted to a lens and through an associated diffraction

5   grating which separates the light according to its wavelength. The separated light impinges upon

6   a linear sensor array of pixels within the unit which identifies both the relative wavelength and

7   the intensity of the light. Each pixel develops a voltage indicative of the light received. An

8   output is taken from each of the pixels to define the spectral distribution of light reflected by a

9   plant. This spectral distribution defines a "fingerprint" of each species of plant to distinguish

10   one species from another. If desired, the fingerprint can be transferred to and plotted on an

11   oscilloscope (wavelength or pixel location vs. magnitude) for immediate visual examination of

12   the resulting fingerprint of the plant, object or tissue.

13   This fingerprint or wide spectrum sensing unit also has the capability of identifying the

14   condition of the plants or tissue. For example, it is believed that the spectral distribution will

15   reflect and identify conditions such as plant stress including a lack of moisture, the need for

16   nutrients, the presence of nematodes, etc. To accomplish this function more accurately, it may

17   be desirable to read more pixels from the linear sensor array or to resort to a higher capacity

18   linear sensor array. To accumulate data reflecting a crop condition, this invention may include a

19   transmittal element such as RS 232 port to permit transmission of the spectral distribution of

20   sample plants within a field to a distant receiver or to a portable computer for subsequent, high

21   speed analysis of the condition of the plants.

22   For plant identification, outputs from the pixel array of the sensing and scanning unit are

converted from analog to digital signals and transmitted to a micro controller or comparator which first memorizes the fingerprint of the plants desired to be identified. Thereafter, the tractor and tool bar moves through the crop to generate time interval reflected spectral distributions (frames) of plants within an agricultural crop. These reflected distributions or fingerprints of each frame of other plants are then compared with a memorized spectral distribution of the plant species sought to be identified. If there is a comparison, the identified plant can be sprayed or acted upon in accord with a preset mode.

Preferably, the digital identifier is a micro controller programmed to first memorize a plurality of wavelengths of light reflected by one or more plants to define the "finger-prints" of the plants of interest, to subsequently receive additional reflected wavelengths from other plants in timed intervals as the vehicle moves through the field and to immediately compare the reflected wavelengths to the memorized wavelengths. If the comparison reflects that the received wavelengths are substantially similar to the memorized wavelengths or finger-prints, the plant can be sprayed, not sprayed or eradicated in accord with a selectable program.

Preferably, but not necessarily, the comparison made by this invention comprises a regression analysis to determine the coefficient of correlation between the memorized and the sensed spectral distributions. If there is a high coefficient of correlation, the micro controller emits a signal to treat the plant in accord with programmed instructions, *i.e.*, a solenoid valve may be opened to permit a pump to spray the identified weed or closed so as not to spray the plant, etc. The limit of the coefficient of correlation may be varied to meet any desired certainty of plant identification.

Accordingly, the goals and objectives of this invention are to provide, among other

1   things,

2   1) a method and apparatus for substantially reducing the cost of applying herbicides to

3   selected or undesirable plants;

4   2) a method and apparatus for substantially reducing the cost of applying herbicides to

5   selected plant species by identifying plants of the selected species and by applying herbicides

6   only to those species;

7   3) a method and apparatus of selectively applying chemicals such as herbicides, growth

8   regulators and inhibitors to selected plants rather than to the entire population of plants within a

9   crop field so as to reduce the cost of chemicals and to reduce the possible adverse environmental

10 effects;

11   4) a very accurate multi-wavelength spectral plant identification and recognition method

12 and apparatus;

13   5) a method and device for reading, transmitting and accumulating the very accurate

14 fingerprint or spectral distribution of plants for analysis of plant conditions such as stress

15 resulting from lack of moisture and nutrients and the presence of nematodes;

16   6) a method and apparatus for identification of stress conditions of a plant prior to visual

17 recognition of such conditions by the human eye through the use of a full spectrum fingerprint of

18 the wavelengths reflected by the plant;

19   7) an apparatus for obtaining objective definitive digital information of the condition of an

20 object or plant which avoids subjective conclusions drawn upon visual personal examinations;

21   8) a multi-wavelength spectral plant identification and recognition device using a low cost

22 diffraction gratings, and a light sensor array;

9) a low cost, wide spectrum electromagnetic plant identification method and apparatus using a low cost diffraction grating, and a light sensor array and a memory device for storing a fingerprint of the spectral distribution of a plant;

10) a wide spectrum electromagnetic plant identification apparatus and method having the ability to memorize a wide spectrum identification of one plant species and to compare that memorized identification with spectrum identifications of a number of plants so as to identify plants that are similar or substantially similar to the memorized plant species;

11) an accurate plant sensing mechanism with a plant action mechanism so as to selectively apply an action to all identified plants of a particular species;

12) a simple, low cost, minimum maintenance apparatus and method for identifying species of plants or other objects at high speed;

13) a simple, lost cost, minimum maintenance apparatus and method for identifying, grading or selecting objects, plant and animal tissue by their color reflections,

14) a low cost spectroscope and identifier that does not require costly physical calibration;

15) a low cost scanning, sensing and identification unit that can use software for calibration and identification of plants, tissue and other objects;

16) a low cost scanning and sensing device having a target or aiming system to identify the area and object whose spectral image is being generated; and

17) a light scanning and sensor unit having a digital identifier for selectively identifying and evaluating objects, plant and animal tissue of different colors for purposes of evaluation, processing, etc.

DESCRIPTION OF THE DRAWINGS

The manner in which these objectives and other desirable characteristics can be obtained from this invention is explained in the following specification and attached drawings in which:

Figure 1 is a perspective view of a preferred embodiment of the invention depicting the plant identification unit and its association with a solenoid controlling a spray rig, the invention being mounted on the tool bar of a farm tractor;

Figure 1a is an enlarged perspective view of the preferred plant identifier unit and spray unit of this invention;

Figure 2 is a block diagram depicting all of the major components of a preferred embodiment of the plant identifier invention;

Figure 2(a) is a chart depicting the functions of the software to be incorporated into the microprocessor;

Figure 3 is a circuit diagram of the preferred electronic schematic layout including the micro controller to be used in the apparatus and method for identification of plants;

Figure 4 is an illustrative drawing of a preferred embodiment of the optical scanning and sensor unit;

Figure 5 depicts "fingerprint" graphs of the cotton plant and the night shade weed actually generated by the present invention in which the wavelength (pixel location) of the plant and weed are depicted on the horizontal axis and the magnitude of the reflected light is depicted on the vertical axis to define the spectral distribution of each, (the data points of the wavelengths are estimates since the pixel output was not calibrated by wavelength);

Figure 6 is block diagram depicting additional components of a preferred embodiment of

1 the plant identifier invention together with alternatives for transmitting the plant's spectral

2 reflectivity, the plant's identity and its condition to a remote data collector such as computer;

3 Figure 6 (a) is a flow chart disclosing additional functions of the software program to

4 enable the microprocessor to collect and transmit data reflecting the plant's color spectrum for

5 the purpose of identifying its species or its condition; and

6 Figure 7 is an illustrative, schematic view of an alternative embodiment of the optical

7 scanning and sensor unit having a light beam for aiming at or targeting the plant or object whose

8 spectral image is being scanned.

DETAIL DESCRIPTION

9 As depicted in Figure 1, the preferred embodiment is mounted upon a tool bar 10 that is

10 affixed to a farm tractor whose left rear wheel is shown at 12. This preferred embodiment

11 includes a plurality of plant recognition or scanning and sensor identification units 20. These

12 units may take various arrangements. In the embodiment shown in Figure 1, these units are

13 positioned side by side and are directed to emit light downwardly and to receive reflections from

14 a row 16. Additional units may be mounted and directed to sense plants on or adjacent the seed

15 bed 18. As will be appreciated, the total number, location and directional mountings of these

16 identification units 20 will be dependent upon the expected size of the plants, the desired

17 accuracy, *etc.*

18 In operation, these identification units 20 will travel with the tractor and tool bar 10

19 down the rows 16 at high speeds of up to 12 miles per hour or more. Consequently, the plant

20 sensing units must scan or take timed plant images (frames) at a very high rate, transmit the

21 images to a comparator or processor to quickly determine if the reflected image is from a plant

1   to which a herbicide or other chemical should be directed. If so, a control or actuation signal is

2   transmitted from a controller to a solenoid 60 to apply a herbicide spray from a pump (not

3   shown) through a nozzle 62 to the plant 80 before the tractor unit has traveled out of spray range

4   of the plant.

THE PLANT SPECIES IDENTIFIER

6   Figure 2 schematically illustrates the design and effective use of the preferred

7   embodiment of this invention for plant identification purposes. After power is applied, the

8   processor initiates its system and program routines. Thereafter, a simple set up is required by the

9   user who must first obtain a "sample" or "standard" species of the plant to be subsequently

10   identified by the invention. A spectral distribution of the light reflected by this "sample" plant is

11   diffracted and placed into the memory of the digital identifier or micro controller 36. An

12   acceptable digital identifier or micro controller capable of serving this function is that

13   manufactured and sold by Motorola, Inc. of Schaumberg, IL under the model designation

14   68HC705C8. This controller 36 has substantial memory and can receive and store a spectral

15   distribution of reflected, discrete wavelengths of reflected light from the plants to be treated. In

16   addition to data memory, it also has program memory and pins to actuate the functions of

17   managing peripheral devices and to carry out the desired comparisons between the digitized

18   fingerprints of the memorized plant species with the reflected fingerprints.

19   To place the "sample" or "standard" species into the programmed controller, the user or

20   farmer positions the sample of the selected plant in front of a sensing unit 20. Natural or

21   enhanced light from a high intensity lamp 24 is reflected from the plant into the scanning and

22   sensing unit 20 (outlined by dotted lines in Figure 2). Side plates 25 form slits or vertical

apertures 26 to insure that the light is directed through a lens 28 having a focal length, preferably

of 1 inch, to a diffraction grating 30. Preferably the diffraction grating has 1,000 lines per meter.

This grating 30 breaks the reflected light into discrete wavelengths and directs it to an array of

linear arranged sensors 32. Those skilled in the art will appreciate that a prism may be an

adequate substitute for the diffraction grating.

The array of sensors may be a TSL 1301 array manufactured and sold by Texas

Instruments, Inc. of Dallas, Texas. It includes 102 sensing elements or pixels, each comprising a

PN junction. Some or all of the sensing elements may be selected to receive the diffracted light

wavelengths and to generate or accumulate, upon inquiry, a voltage charge proportional to the

intensity of the received wavelength. To reduce the memory required and for ease of

programming, 32 of the 102 pixels have been found to be sufficient for plant identification

purposes. This allows for fingerprint definition of the plant comprising 32 different wavelengths

and a rather accurate spectral distribution of the plant. Generally, these 32 wavelengths will

represent a very wide, if not full spectrum of light extending from about 400 nanometers to

about 1100 nanometers. If desired, other sensor arrays could be used to identify shorter or

longer wavelengths including infra red lengths.

In operation, each of these pixels develops a voltage that correlates to the quantity of

light received. This developed voltage by each pixel can be read by the micro controller 36. For

this purpose, controller 36 has a switch 64 (see Figures 3 and 4) to enable the farmer to manually

instruct the unit to pulse the sensor array 32 to obtain spectral distribution of the "sample" of

"standard." This pulse signal will sequentially generate an analog output from all of these pixels

to the sensor array 32 and transmit them to an analog-to-digital converter 34. The converter 34

1   will then direct digital information corresponding to the magnitude of the voltage developed by

2   each pixel into one of 32 memory elements of the micro controller 36 for storage and

3   comparison purposes.

4   When stored (memorized), the micro controller 36 then has a spectral distribution or

5   "fingerprint" of the wavelengths reflected by the plant to be identified in the subsequent

6   fingerprinting operation in the field. This memorized print thus becomes the "standard" against

7   which subsequent or fingerprints are compared. The spectral distribution of the plant to be

8   identified can also be transmitted to the other sensing units 20 via a serial communication port in

9   the 68HC705C8 micro controller. This port can be tied to the corresponding ports of each light

10   scanning and sensor unit 20 and an appropriate program can be written to allow any one of the

11   units to communicate the spectral distribution of the wavelengths reflected by the plant to each

12   of the other units in the system for ease of set up.

13   It should be noted that plants to be identified do not have a uniform finger print under all

14   soil, moisture and atmospheric conditions. Thus, the present invention permits the farmer to

15   specifically place in memory the spectral distribution or fingerprint of the plants to be selected

16   for treatment on his farm under the then existing conditions. Such facilitates an accurate plant

17   identification and minimizes error that may result from soil moisture conditions, fertilizers,

18   pests, temperatures, etc. Similarly, the capability of this invention to receive and memorize

19   specific plant fingerprints from the actual farm to be sprayed eliminates the need and costs to

20   develop predetermined fingerprints for dozens of plants. For the first time, such can be done on

21   site. Significantly, an original aspect of this invention is its ability to generate its own

22   fingerprints by directly focusing on the plant, tissue, object or an actual replica or photo

representative thereof without the use of prerecorded digital or analog data points. Figure 5

depicts the spectral distribution or graphical fingerprints of two plants that many farmers would

like to identify. One curve reflects the fingerprint of a cotton plant that may be used to avoid

application of herbicides or to apply a growth inhibitor. The other curve reflects the fingerprint

or spectral distribution of a prevalent, noxious weed, the nightshade in West Texas, these

distributions being taken by the present invention. From a comparison of these two curves, it is

apparent that they are different and that a regression analysis would generate a very small

coefficient of correlation advising of the dissimilarity of the two plants. After the plant, such as

the night shade has been fingerprinted by memorizing its wavelength output, the unit is ready to

identify all of the plants in a field having the same finger print or "spectral distribution" of

wavelengths. This comparison of the spectrum distribution of reflected light from nightshades

with that from cotton in Figure 5 manifests the different fingerprints of these two plants so as to

permit their selective identification. It also demonstrates a capability to permit set up and

identification of each plant by a sample leaf. Alternatively, the generation of a single fingerprint

on an oscilloscope will permit immediate visual identification of the type or condition of the

plant or tissue if such is desired.

Assuming that the farmer's decision is to spray all of the plants of the memorized species

with a herbicide such as Roundup®, the farmer fills the herbicide reservoir or sump S of Figure

2 with a proper solution of Roundup®, initiates a pressure buildup by the pressure pump P

which is connected to a solenoid valve 60 having a spray tip 62 which is directed at the same

area and along the same axis as the scanning unit 20. A solenoid driver 44, controlled by the

micro controller 36 activates the solenoid valve 60 to spray the herbicide on the plant.

1   To insure that the memorized plant is identified and sprayed before the tractor unit

2   passes the plant, the micro controller 36 must first identify the plant as one to be sprayed and

3   then immediately actuate the solenoid valve 60.

4   To obtain this instantaneous, but very accurate plant identification, the microprocessor

5   36 is programmed to initialize reading the individual pixels of the linear sensor array 32

6   preferably at least once every 25 milliseconds. Such has been calculated to permit identification

7   of a plant having a leaf width of approximately 2.5 inch width while traveling at speeds of

8   approximately 5 miles per hour. Thereafter, each clock pulse serially reads the voltage generated

9   by each pixel or sensor to define a spectral image, frame or fingerprint. This voltage is

10   converted to digital information and then stored in other data memory locations of the micro

11   controller 36. After the sensors are read and their output stored in the micro controller 36, the

12   memorized (standard) spectral distribution is compared with the spectral distribution of that

13   reflected by the last plant. While only a few wavelengths could be compared to obtain a

14   reasonably accurate determination of the similarity of the memorized plant distribution with that

15   of the reflected plant, the preferred embodiment of this invention includes programming of the

16   micro controller 36 to run a statistical regression analysis comparing the data points of the

17   spectral distribution or wave chart of the memorized plant with the reflected spectral distribution

18   of each time out-put or frame of the reflected spectral distribution. If the coefficient of

19   correlation between the two distributions is high or greater than the pre-set limit so as to reflect

20   similarity or identity, the micro controller 36 generates an output to the solenoid driver 44 to

21   activate the solenoid valve 60 to apply spray.

22   Fast acting solenoids such as those sold by Peter Paul Electronics Co. Inc. under the

trade mark or model number 32X005806 are sufficient. Spray tips 62 can be selected to apply a very narrow target spray or a wider one depending on the desires of the farmer and the need for accuracy. For example, if one is applying a Roundup® herbicide to nightshade weeds in a Roundup® variety of cotton, some over-spray will not damage the crop and will merely result in a limited over-spray that affects costs and pollution in a limited way. On the other hand, the required coefficient of correlation between the two plant fingerprints may be increased to obtain higher certainty of plant recognition and a finer spray tip can be selected to more accurately direct the herbicide to the identified weed and nothing else. Those acquainted with the art will also recognize that a timing of the activation and duration of the solenoid can be used to actuate the solenoid at a later time or distance so that the solenoid can be activated a fixed distance after the weed is detected thus allowing the spray to take place a fixed distance behind the identification to avoid contaminating the optical system with chemical. If the solenoid is of a type to be deactivated, then the program of the micro controller can include such a function.

It should be appreciated that the micro controller 36 must be very fast and should read the memorized images and run a regression analysis numerous times per second to insure that each weed or plant is scanned for its spectral distribution and considered for spray by the regression analysis.

Figure 3 depicts an electronic circuit board design 46 that has been demonstrated to be effective for the purposes of this invention. The controller or digital identifier 36 is located on the left side of the board 46. Leads 48 and 50 prepare (SI) and initiating (CLK) data communication of the analog magnitude contained in each of the sensors of the array 32. This accumulated data is communicated to the analog-to-digital converter 34 via lead 52. The analog

to digital converter 34 converts the analog signal to a binary digital signal and delivers the result to port C, *i.e.*, pins 21 to 28 or (PC0 through PC7), of the micro-controller 36. A timer built into the micro-controller 36 repeatedly generates a clock pulse to take a new fingerprint of its visual area and deliver the fingerprint or spectral distribution in binary form to the micro-controller 36.

The reference circuit 54 at the lower right of Figure 3 supplies an upper reference for the analog to digital converter. This is set to the highest expected value of the analog output signal 52.

After each time interval light data is fed into the micro controller 36, it runs a preprogrammed regression analysis to determine the coefficient of correlation between the spectral distribution of the memorized plant and the spectral distribution of the plant of the new time interval frame. If the coefficient of correlation is equal to or greater than a predetermined value, the micro controller emits a signal through the solenoid driver 44 to activate the solenoid 60 to spray identified nightshade plant. Preferably the result of the correlation computation is converted to an integer factor that is representative of the coefficient of correlation so as to simplify the spray decision and avoid a decimal number.

The pre-set value or correlation limit established for actuation of the solenoid driver 44 can be increased as desired through discriminating switches 56 and 58. The non-grounded side of the more discriminating switch 56 is connected to pin 15 of the micro-controller 36. When this pin is activated, the program in the controller increases the limit of the correlation coefficient by 1/256. When pin 16 of the micro-controller is activated by pressing the less discriminating switch 58 the correlation coefficient limit is decreased by 1/256. The increment value, 1/256, may be decreased by a software change for greater accuracy.

1   A standard switch 64 may be used to instruct the micro controller 36 to memorize the

2   spectral sample (or standard distribution) in a specified portion of its memory to be used in

3   subsequent calculations of the correlation coefficient or its factor. This allows the unit to spray

4   only things that are like the sample or only things that are not like the sample. As those skilled

5   in the art will appreciate, an alternative method of accomplishing this task would be the use of

6   switches connected to a micro controller pin and software to change the logic mode. For

7   example, instead of identifying plants to be sprayed with a herbicide, the invention can be set up

8   to identify the planted or money crop—and use an inverter to spray all other vegetation. Thus,

9   the mode switch 66 can be used to change from the mode that actuates the solenoid 60 (Figure 4)

10   when the correlation coefficient limit is exceeded to a mode where the solenoid 60 is deactivated

11   when the correlation coefficient limit is exceeded.

12   To facilitate one's understanding of this invention, the flow chart of Figure 2(a) further

13   discloses the functions of the software of the micro controller 36 as described herein. In

14   addition, these functions have been incorporated into the following machine code for the

15   identified Motorola micro controller MC68HC705C8 in a manner to utilize 32 pixels of the light

16   sensor array so as to 1) effectively memorize a spectral distribution of a sample plant, 2) to

17   subsequently take spectral distributions (fingerprints) of other plants, 3) to compare those plants

18   with the sample, and 4) to identify the other plants that are of the same species or spectral

19   distribution as the sample.

MACHINE CODE

21   S1130100A620B777A60FB7BBA600B7BFC61FDFAA46
22   S113011082C71FDFA6A7B704A600B706A6E7B705E0
23   S11301203F02A690B7BBCD044ECD0169CD01840D2D
24   S1130130000BA600B7BFB778B7BDCC0141A601B785
25   S1130140BFCD045D00BF022000CD04D9CD04C0CDD5

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1    S1130150019FCD01CECD01FDCD022D1B00BE42B3CA
2    S1130160772503CD04F2CC0126060115003B1410BB
3    S11301703BB677AB01B777A1402508A640B77720F7
4    S113018002113B81080115023B14123BB677A00112
5    S1130190B777A1012208A601B7772002133B81A6F5
6    S11301A000B7B5B7B4B7B3BFBCAE425CA363271DF9
7    S11301B0BFB6F6FECD0504BBB5B7B5BFBEB6BEB976
8    S11301C0B4B7B4A600B9B3B7B3BEB620DE81A600F7
9    S11301D0B7B2B7B1B7B0BFBCAE785CA399271DBFA7
10   S11301E0B6F6FECD0504BBB2B7B2BFBEB6BEB9B15A
11   S11301F0B7B1A600B9B0B7B0BEB620DE81A600B7CD
12   S113020036B737B738BFBCAE425CA363271EBFB650
13   S1130210F6EE36CD0504BB36B736BFBEB6BEB9372B
14   S1130220B737A600B938B738BEB620DD81B638B7BF
15   S11302303FB637B740B636B741CD0555B63FB738A8
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Figure 4 depicts one mechanical arrangement for the scanning and sensor unit 20. As shown, each entire light scanning and sensor unit 20 is contained in a housing 22 that is formed of rectangular tubular stock. To the rear of the sensor unit 20 is mounted the circuit board 46. A light source 24, preferably Sylvania lamp MR 6 is affixed in similar tubular stock adjacent the housing 22. Light is reflected from an object to the right and is reflected through the shield 68 and apertures 26, through lens 28 and diffraction grating 30 which diffracts the light the longer wavelengths through a larger angle than the shorter ones. The result is a rainbow of light on sensor array 32 with infrared to the bottom and ultraviolet at the top and all parts of the visible electromagnetic spectrum in between.

ALTERNATIVE EMBODIMENTS, MODES AND METHODS.

1   Persons skilled in the art will appreciate that the disclosed scanning and identification

2   invention can be utilized in several ways and is not limited to a specific mode. As earlier

3   mentioned, a mode switch 66 can be used to control the output of the micro controller so that it

4   sprays the vegetation having a high correlation coefficient to the sample, or so that it does not

5   spray that vegetation. In addition, the planted crop can be fingerprinted, identified and sprayed

6   with growth inhibitors, etc. rather than herbicides. Another alternative mode of operation of this

7   invention can be obtained by placing the fingerprint of two or more samples of plant species into

8   memory, and programming the micro controller to run two or more comparisons or regression

9   analysis before issuing a determination to actuate the sprayer or other device. This mode and

10   modification can take several forms. For example, if a farmer desires to spray two weeds with

11   different herbicides, he could associate one regression analysis with one solenoid driver and

12   herbicide sprayer and a second regression analysis with another solenoid driver and herbicide

13   sprayer. Such is a desirable capability when different herbicides have different effectiveness on

14   different plants. In addition, the farmer might hold a soil sample under the sensor unit and place

15   its spectral distribution in memory. Should the comparator then determine that the compared

16   time interval spectral distribution is the same as that of the memorized soil sample, the

17   microprocessor can be programmed not to spray. This mode would permit the spraying all

18   vegetation, but not the bare ground.

19   In addition to the soil sample spectral analysis, a farmer might store a second distribution

20   of the cotton plant of Figure 5. After the microprocessor runs a regression analysis comparing

21   the reflected distribution with each of the soil and cotton plant distributions, it can easily be

22   programmed or provided with a separate logic board to activate the sprayer only if neither cotton

1   nor soil is detected.

2   Those skilled in the art will also appreciate, that rather than using a single micro

3 controller 36 to memorize two or more plant or soil spectral distributions, one might use two or

4 three units and focus them on the same frame or image. Each unit could memorize a single

5 distribution and identify a single object or plant species. The output of these separate devices

6 could be input to a logic board with switches that would permit any of the commonly known

7 logic decisions such as those of AND, NAND, OR, NOT etc. logic gates. In addition, the present

8 invention can take many forms and utilize numerous components that perform in substantially

9 the same way to achieve substantially the same result. For example, numerous controllers or

10 digital identifiers could be used in lieu of the Motorola controller disclosed in this specification.

11 Those skilled in the art will appreciate that the essential functions of the digital identifier or

12 controller 36 are those of providing memory for the storage of the spectrum data and of the

13 program steps reflecting the desired functions as well as logic circuitry having the ability to

14 perform the desired functions and comparison. Such may take the form of an arithmatic logic

15 unit or its equivalent. In addition, the digital identifier should have an Input/Output (I/O)

16 capacity to receive data from the sensor array and to control at least one peripheral device such

17 as the sensor array 20. Preferably, the identifier will have input and output pins to activate the

18 solenoid and to receive the data reflecting the spectral distribution or to transmit the information.

19 Consequently, any of the various micro controllers, computers, microprocessors and digital

20 signal processors (DSP) which have the necessary components will be acceptable alternatives.

21 Alternatively these individual devices such as the memory and I/O devices can be purchased

22 separately and wired together to accomplish the necessary functions.

More specifically, one alternative is a Digital Signal Processor (DSP) Model No TM320F240 which is made and sold by Texas Instruments of Dallas, Texas. In addition, Model No. TMS 320F243 has the capabilities to meet the requirements of this invention. These units provide enhanced features such as high speed (20 megahertz), additional storage and the ability to point to two sets of data simultaneously. In addition to the use of alternative processors, those skilled in the art will appreciate that different lamps may be utilized and that in many cases, the lamp will not be necessary with natural light being sufficient. Too, alternative array devices that are more sensitive or have different pixel counts may be utilized instead of the TSL 1301. For example, TSL 1401 from Texas Instruments, Inc. of Dallas, Texas will permit the collection of 128 wavelength sectors rather than 102. And though the invention preferably uses a regression analysis to develop a coefficient of correlation, the invention may well provide the desired accuracy of plant identification by merely comparing only three or four data points of the light spectrum. This could be accomplished by use of 3 or 4 discrete sensors properly located to sense the desired wavelengths of light and a simple comparison program that does not require a regression analysis or computation of the coefficient of correlation. A multiplicity of linear arrays or an area array, could be used to reduce the number of sensor units, with each column representing spectral information equivalent to one sensor unit. Advantage can also be taken of the opportunity to develop statistics regarding the precise location of the edge of the canopy and the texture of the field of view with such numerical methods as fast Fourier transforms, convolution, and other recognition methods including statistical process control techniques such as mean and standard deviation control chart theory. With a multiplicity of elements, or an area array in which each column represents the spectral reflectivity of a point on a line across the crop

row, repeated samples, taken in time as the motion of the unit continues through the field, spectral image data is generated and digital filtering methods can be applied to get an image of the desired object, weed or other plant or feature. Another alternative would be to utilize a previously memorized spectral distribution in the form a memory or data card to set up the unit and to establish the initial electronic memory or finger print rather than using an actual plant. Illustrative of further alternatives is the use of digital filtering and transforms which can be used to enhance recognition capability.

An alternative embodiment of the scanning and sensing unit 20 is depicted in Figure 7. This improved alternative 120 includes an aiming or target light to facilitate identification of the plant or object which is being scanned. This unit includes a housing 122 which houses two lenses 140 and 142 that are positioned equidistant from an aperture plate 125. Affixed to the housing 120 in any conventional manner is a light source 124 that is focused upon a plant 80. Light reflected from the plant passes into the housing 122 through the lens 140, the aperture plate 125 and the second lens 142 to the diffraction grating 130. Segments of this reflected light are diffracted upon the sensor array 132 which is offset from the housing 122. In operation, this unit works in a manner similar to that of scanning and sensing unit 20.

In addition, however, a Target Light is mounted to the right of the housing 130, as viewed in the drawing. This light source, when activated, transmits light in the opposite direction of the reflected light, i.e., it passes into the housing 122, through lens 142, aperture plate 125, lens 140 where it is focused on a part of the plant 80. When the Target Light source is activated in any conventional manner, the focused light will be apparent on the same portion of the plant as the light would be reflected from lamp 124. Accordingly, when activated, the target

1   light source will identify the actual target of the scanning and sensing unit 120. Importantly, this

2   target light will inform the user whether the spectral sample is of the plant leaf, stem, flower etc.

3   Preferably, the Target Light and the lamp 124 will not be actuated at the same time.

4   Those skilled in the art will appreciate that the focal point of the target light and its

5   distance from the housing will be dependent on the selection of the lens 140 and 142 and their

6   placement within the housing.

THE PLANT CONDITION IDENTIFIER AND TRANSMITTER

8   Another embodiment of the invention is depicted in Figure 6. This embodiment depicts

9   additional components for and methods of using the digital identifier to collect and transmit

10   plant fingerprints or wide spectrum data points of plant or tissue immediate evaluation or for

11   accumulation and subsequent analysis of the object.

12   In this embodiment, a toggle switch 80 is used to switch the controller program from one

13   of plant identification to one of plant analysis, *i.e.*, to the accumulation of a fingerprint or wide

14   spectrum data point collection and its transmittal to an oscilloscope, computer or to a memory

15   device for analysis. Alternatively, the data can be communicated to a portable computer

16   physically connected to the device for plant condition analysis.

17   Physically, this embodiment is physically similar to the plant identification embodiment

18   in that most of the same components are utilized. In addition, this embodiment has the mode

19   switch 80 to activate the transmittal program routine and a send or transmit switch 82. When

20   activated the transmit switch 82 instructs the processor 36 to serially transmit the entire full

21   spectrum of the plant's condition to a RS 232 port 92 which may be connected to a portable

22   computer or a radio transmitter or a digital cellular device. In addition, the processor 36 may be

programmed to receive a signal, such as character "0" from the computer and to serially transmit the entire full spectrum of the plant sample to the computer where it may be stored for later analysis.

In operation of this embodiment, a program is written to reflect the software functions set forth in Figure 6(b) which is then stored in program memory of the processor 36. When the mode switch 80 is activated, the light sensor accumulates a voltage charge in each of the pixels to reflect the spectral distribution of the light reflected by the plant. Such charges are sequentially sent to the analog to digital converter 34 and then transmitted to data storage memory locations within the processor 36. Preferably sample distributions are continuously taken, converted and stored for possible transmission to a memory device through the RS 232 port.

The data is transmitted upon activation of the switch 82 or upon a reception from the computer or cellular device connected to the RS 232 element 92. In addition and as an alternative to the use of the processor 36 to effect this transmission function, one may obtain the analog output from the sensor array 32 by a direct connection at 94 to the output of the sensor 32. Such a connection has been helpful in directly connecting the unit to an oscilloscope (not shown) to visually examine the spectral distribution of the light reflected by the plant. If desired, a digital oscilloscope could be used to convert the analog information to digital for further use and analysis by external means. In addition, a parallel connection 96 could be taken from the A to D converter 34 and directed to an I/O card of a computer or other device.

Another modification to this embodiment is the use of a larger linear or area array. Preferably model TSL 1401 or Texas Instruments, Inc. would be utilized because it has 128

1   pixels which can be utilized to obtain a more definitive fingerprint of the plant for analysis

2   purposes. Significantly such may be most helpful in ascertaining the degree of stress or other

3   conditions of the plant. In the event such a sensor is utilized, it will also be desirable to use an

4   enhanced processor such as DSP Model No. TMS320F240 previously mentioned.

5   Like the machine code program previously set forth in this application for the plant

6   identification routine, persons skilled in the art can easily formulate the collection and

7   transmittal program or routine for use in conjunction with either the single sample switch 82 or

8   the continuous mode switch 80.

9   In application, it is intended that the entire identification and transmittal units be

10   incorporated into a light weight hand held case to enable plant inspectors to carry the units to the

11   field, obtain spectral distributions of one or more plants or any part there of and to transmit such

12   distributions to a memory device for subsequent analysis of the plant's condition. Alternatively,

13   such a unit could also be mounted on tool bars which are carried down the row with a computer

14   or controller transmitting the character "0" to the unit to effect transmittal or downloading of one

15   or more sample spectral distributions of the plants or crops at various points.

16   In implementing these inventions, those skilled in the art will also appreciate that the

17   spectrometer or scanning and sensing unit 20 of my invention may be calibrated. However,

18   calibration may impose additional costs. On belief, most if not all commercial spectrometers are

19   calibrated. However, an alternative is to avoid calibration and to approximately align a segment

20   of light rays, for example visible red light with, for example, the center pixel of the sensor array

21   32. Such should always be sufficient when the same spectral identifier unit is being used for the

22   sample and for the other objects of the population. This, for the reason that the same instrument

will always diffract the same wavelengths to the same pixels and the resulting comparison will always be comparing the output of each wavelength of the sample with the output of the same wavelength of the next object of the population.

However, when different instruments using an uncalibrated sensor and scanning unit of my invention are used to generate the finger prints of objects or tissue, it may be advantageous to insure that the digital identifier or comparator 36 or computer properly compares data points generated by one scanning unit 20 with the appropriate data points generated by another sensing and scanning unit 20. For example, the magnitude of the voltage generated by a diffracted wave length segment of one sensing and scanning unit 20 should be compared and correlated with the magnitude of the voltage generated by the same wave length segment on the other sensing and scanning unit 20. Such would inherently result when using calibrated scanning and sensing units. However, if one does not desire to use calibrated units or if one does not use the same identifier unit to compare the fingerprints, it may be desirable to develop software that will modify the wave length data points of the fingerprints of one identifier to match the corresponding wave length data points of fingerprints of other identifiers. Such modifications would require software shifting of the data points to insure that similar or identical sets of wavelengths are shifted to a fixed standard for all manufactured units. Preferably, such software would be incorporated into the memory of each of the digital identifiers 36 at the time of manufacture and such would be a low cost form of calibration. Alternatively, such software may be developed for a computer receiving transmitted fingerprints for analysis.

Those skilled in the various arts will also appreciate that the present inventions have broad uses in other agricultural operations. For example, they might be used to identify specific

1   soils on a farm to selectively apply certain fertilizers to soils having certain colors. It may well

2   be used to identify and sort vegetables, fruits and other products by color and ripeness.

3   Similarly, the invention may well find applicability in numerous industrial, medical and

4   biological applications of collecting, identifying or processing products and objects including

5   fluids and animal tissue by color. Such uses may include the early detection of skin cancers.

6   Another diverse application would relate to color bar coding in which this invention would

7   facilitate the encoding and reading of far more information that the present black and white bar

8   coding. Other uses and modifications of this invention such as these will be apparent to those of

9   ordinary skill in the art from the contents of this application.

I Claim:

1.   A high speed, low cost, wide spectrum plant identifier apparatus adapted to be

mounted on a farm vehicle for selectively identifying plants within a field by species and for

selectively applying chemicals thereto for the purposes of reducing the chemical costs and the

excessive chemical application which may otherwise result in pollution problems, said apparatus

5   comprising:

6   a) a sensing device for receiving reflected light from a plant, said device including a

7   diffraction element for separating the reflected light into segments of different wavelengths and a

8   linear sensor array having elements positioned to receive the segments and to measure the

9   relative magnitude of such segments to define a wide spectral distribution of the plant;

10   b) a digital identifier connected to said sensing device and having a memory for

11   memorizing a spectral distribution of light representing a first plant species from the field, and